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To cite this article: S Yu Belyaev *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **718** 012003

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Research of Load Distribution Between Working and Backup Rolls of Sheet Levelling Machine with Regard to Gaps and Heat Strain

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Abstract. The article addresses to distribution of loading between working and backup rolls of sheet levelling machines taking into account presence of initial gaps between them and heating that occurs during the straightening process, which is especially important in case of the high-temperature straightening. For levelling machines with a single row of backup rolls calculated dependencies were obtained to evaluate loads suffered by backup roll taking into account factors under this study and the analysis of results for the 9-roll straightening machine were carried out. The analysis showed a significant overload suffered by backup rolls.

Levelling is the final deforming operation in the process of rolled steel sheets production. It is straightening that ensures elimination of the key defects of steel sheets – wavy edges, center buckles, camber. Operating practice of levelling machines at numerous iron making and non-ferrous metallurgy plants demonstrates that setting of roll-type levelling machines (hereinafter – RLM) is quite a labor-intensive procedure [1], since quality of the straightening process and subsequently quality of the finished product depends on many factors, part of which are rather variable and impossible to control in an unbiased manner what makes them hard to take into account. The most relevant factors include the initial gap between the backup and working rolls and roll temperature values.

This challenge bears relevance especially for levelling machines intended for straightening of steel sheets under small series production conditions, which are typical for the plants manufacturing sheets from specialized steel grades or non-ferrous metals. For such plants, setting of RLM at a high level of quality considering unstable operating conditions of the rolls in terms of temperature is quite a challenging task. It takes to make certain corrections involving continuous fine adjustment or to apply additional straightening to the product. The mass and large series production of steel sheets demonstrate that the indicated factors of instability have certain impact only during the initial period of straightening of the sheet batch; the temperature condition of the roll operation becomes stable afterwards.

Therefore, the present research is aimed at identifying the heat strains of rolls during sheets straightening and evaluating the load distribution between working and backup rolls of RLM being exposed to straightening force.

The present research set a model of levelling machine with one row of backup rolls and their coaxial arrangement with the working rolls as its subject (Figure 1 (a)).

A 9-roll straightening machine designed by SKMZ (Starokramatorskii machine-building plant) was taken as a prototype of this analytical model; its rolls are $D = 400$ mm in diameter and the mandrel is



2000 mm long. The roll pitch of RLM under research makes 460 mm and the distance between centers of working roll supports – $l = 2800$ mm.

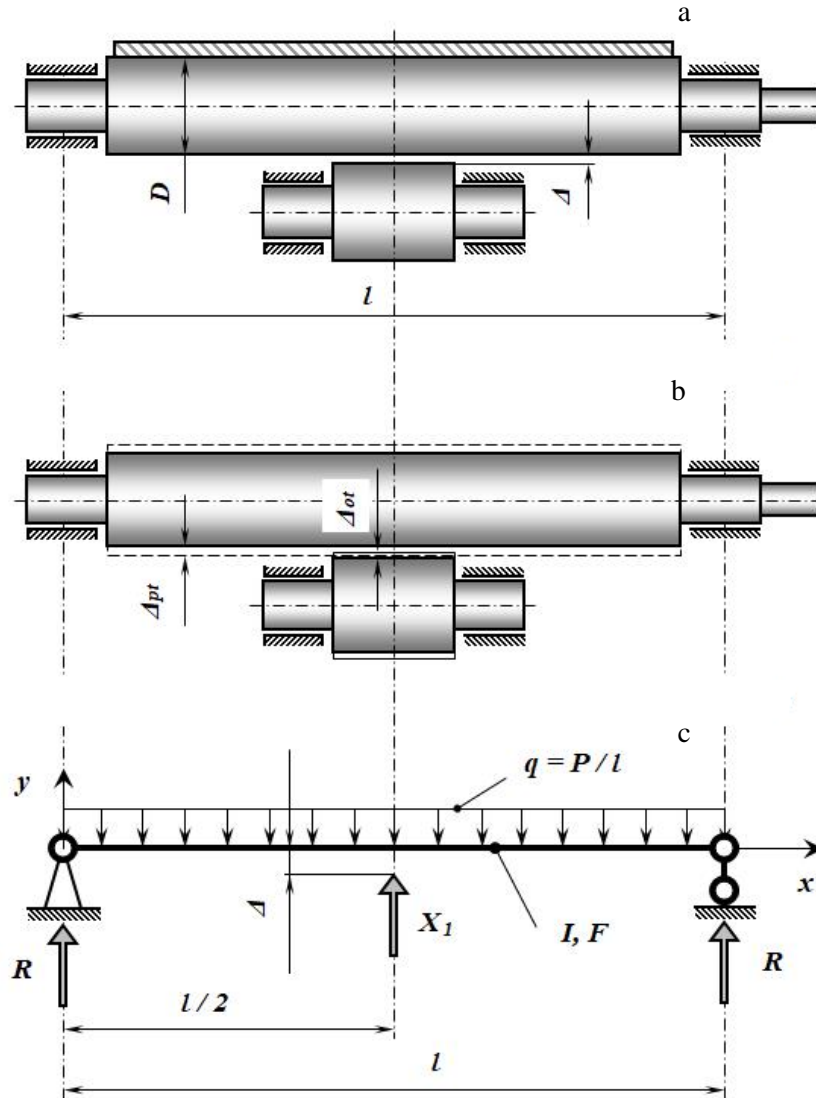


Figure 1. Design and analytical models for the working and backup roll system of sheet straightening machine: (a) – design model of the roll system; (b) – formation of heat strain; (c) – analytical model of the roll system.

The backup rolls $D_{br} = 450$ mm in diameter are installed in one row coaxially with the working rolls, excluding the first one and the last one. This RLM is intended for straightening of sheets up to 22 mm thick, up to 1800 mm wide made of alloys with deformation resistance up to 500 MPa. For the conditions described above, the maximum force at the 3rd roll which is exposed to the maximum load shall amount to 1900 kN.

There is a well known classical solution for the force distribution at loading of continuous beam by method of three torques [2]. This solution suggests that the backup roll should be exposed to $5/8 = 0.625$ or 62.5% of the straightening force applied to one working roll. At the same time, this solution doesn't consider gaps between the rolls and possibility of their heat strain.

The total Δ between the working and backup rolls during operation (Figure 1 (a) and (b)) is defined by the algebraic sum of the initial gap Δ_0 and the total heat strain of both rolls Δ_t :

$$\Delta = \Delta_0 - \Delta_t. \quad (1)$$

The initial gap Δ_0 is defined by the total value of mounting clearance, value of the rolls re-grinding and their wear. As a rule the complete initial gap amounts up to 0.1-0.3 mm.

The total heat strain of the working roll Δ_{pt} and the backup roll Δ_{ot} (Figure 1 (b)) can be defined using the following formula

$$\Delta_t = 0.5D\alpha_t t_{wr}(1 + k_D k_t). \quad (2)$$

where α_t – coefficient of linear expansion, 1/degree; t_{wr} – average increase in temperature of working roll across its section, degree; $k_D = D_{br}/D$ – relative diameter of the backup roll taken as such based on design of straightening machine within 1.0-1.15 for usual RLM design and up to 2.0 – for machines with the increased backup roll diameter; $k_t = t_{br}/t_{wr}$ – relative increase in temperature of the backup roll.

In this research, the average value of temperature increase across the section t_{wr} was a variable factor taken in the range 20°-300°. For the steel grades applied for manufacture of straightening machine rolls, the values of linear expansion coefficient at the given temperature conditions according to the reference data [3] amount to:

$\alpha_t = (1.05 \dots 1.19) \cdot 10^{-5}$ 1/degree – for alloyed structural steel type 12XH2A (12HN2A);

$\alpha_t = (1.19 \dots 1.55) \cdot 10^{-5}$ 1/degree – for bearing-type structural steel type IX15 (WX15);

$\alpha_t = (1.10 \dots 1.30) \cdot 10^{-5}$ 1/degree – for steel intended for roll-making type 9X.

Lower values of the linear expansion coefficients relate to the temperature range 20°-100°, and higher values – to the range 20°-300°.

Temperature distribution between the working and backup rolls can be found based on experimental data obtained via measuring the roll temperature. Should such data be unavailable, one can use the analogy with temperature distribution between working and backup rolls in the 4-high stand Quarto. Calculation of the roll system deformation is known to take the temperature increase of the backup roll in relation to the working roll considering coefficient 0.25 [4], i.e. $k_t = 0.25$. For RLM, a recommendation to select the value of relative temperature increase of the backup roll within the range $k_t = 0.2$ -0.3 is feasible. Lower values k_t can be applied to the backup rolls of higher diameter in comparison to the working rolls, while higher values k_t – to RLM in which backup rolls are arranged in a staggered way.

A special calculation was made for 9-roll straightening machine of SKMZ design, which was taken earlier as a prototype so that to assess the total impact of the initial gap and heat expansion of the rolls. The calculation was made for various levels of temperature increase of the working roll within the range 20°-300° with a pitch of 20°. The relative backup roll diameter was taken based on design parameters of RLM $k_D = D_{br}/D = 450/400 = 1.125$, and the relative backup roll temperature increase $k_t = t_{br}/t_{wr}$ was taken as 0.25. Table 1 shows the calculation results for the rolls made of steel 12XH2A (12HN2A), with the initial gap 0.1 mm and 0.2 mm.

Negative values of the total gap between working and backup rolls means there is no gap and both rolls are preliminarily loaded without any external load/impact. According to analyses of the obtained results, increase in temperature of the working roll up to 40°-80° makes the heat strain of the roll system compensate the initial gap Δ_0 , and force distribution between working and backup rolls is nearly equal to a theoretical value. Increase in temperature of the working roll over 100° causes rapid growth in preliminary load of the rolls.

With the obtained data on the value of the total gap between the rolls taken into account, an analytical model for the working roll was formed, represented at Figure 1 (c). In this model the working roll is represented as a simple beam with length l round in section, with the area F and inertia moment I . The beam is loaded with an equally distributed load $=P/l$, where P – strip levelling force applied to the working roll. The impact applied by the backup roll to the working roll is accounted by the statically indeterminate force X_1 , which becomes effective only upon reducing gap Δ to zero, and reaction of the bearing support of working roll makes R .

Statically indeterminate force X_1 was determined from solution of the classical equation of the force method [5], since the gap between the rolls made it impossible to use a theorem related to three torques in this case:

Table 1. The total heat strain and total gap between working backup rolls.

Increase in working roll temperature t_{wr} , degrees	Total heat strain of the rolls Δ_t , mm	Total gap between the rolls Δ , mm with the initial gap	
		$\Delta_0 = 0.1$ mm	$\Delta_0 = 0.2$ mm
20	0.054	0.046	0.146
40	0.108	-0.008	0.092
60	0.161	-0.061	0.039
80	0.215	-0.115	-0.015
100	0.269	-0.169	-0.069
120	0.354	-0.254	-0.154
140	0.413	-0.313	-0.213
160	0.472	-0.372	-0.272
180	0.530	-0.430	-0.330
200	0.589	-0.489	-0.389
220	0.671	-0.571	-0.471
240	0.732	-0.632	-0.532
260	0.793	-0.693	-0.593
280	0.854	-0.754	-0.654
300	0.915	-0.815	-0.715

$$\delta_{11}X_1 + \Delta_{1P} = -\Delta, \quad (3)$$

from which:

$$X_1 = \frac{-\Delta - \Delta_{1P}}{\delta_{11}}, \quad (4)$$

where Δ_{1P} – displacement from application of external forces towards statically indeterminate force X_1 , mm; δ_{11} – displacement from application of single force towards statically indeterminate force X_1 , mm/N.

Displacement from application of single force and external force was defined using standard methods of material strength. As a result the following ratio were obtained, considering both bending torques and lateral forces:

$$\begin{aligned} \Delta_{1P} &= -\frac{5}{384} \frac{Pl^3}{EI} - k \frac{Pl}{8GF}, \\ \delta_{11} &= \frac{l^3}{48EI} + k \frac{l}{4GF}, \end{aligned} \quad (5)$$

where E , G – elasticity modulus and shear modulus accordingly, MPa; k – coefficient related to the form of cross-section during shear; for round section $k = 1.185$.

Should the calculation of displacement consider only bending torques, the represented ratio shall retain only the first summands.

Upon substitution of displacement values into the formula intended to find the statically indeterminate load and transforming, we shall obtain the following ratio:

- considering only bending torques

$$X_1 = \frac{5}{8} P - \Delta \frac{48EI}{l^3}, \quad (6)$$

- considering both - bending torques and lateral force

$$X_1 = 0.25P \frac{5\left(\frac{l}{D}\right)^2 + 6k(1+\nu)}{2\left(\frac{l}{D}\right)^2 + 3k(1+\nu)} - \Delta \frac{3\pi ED^2}{2l \left[2\left(\frac{l}{D}\right)^2 + 3k(1+\nu) \right]}, \quad (7)$$

where ν – coefficient of lateral deformation (Poisson's coefficient).

For the steel grades used for manufacture of straightening machine rolls, values of mechanical properties according to the reference data [3, 5] at temperature range 20° up to 300°C are as follows:

- Poisson's ratio $\nu = 0.28 \dots 0.30$;
- elasticity modulus $E = (2.11 \dots 1.90) \cdot 10^5$ MPa.

Should the gap between the rolls be equal nil (provided that we consider only bending torques), one shall obtain the force at the backup roll equal to 0.625 from the straightening force at the working roll, which gives a clear correspondence with the above mentioned classical solution of this task [2]. In case we consider both - bending torques and lateral forces for the 9-roll straightening machine under the study under the similar conditions, the proportion of complete straightening force applied to the backup roll shall amount to 0.619, which is quite similar to the well known solution (error not more than 1%).

The load suffered by the backup roll is convenient to calculate as a relative value instead of absolute force values – in certain proportion from complete force applied to the working roll, through the ratio X_1 / P . As such, the relative force at the backup roll in its extended form shall amount to:

- considering only bending torques

$$\frac{X_1}{P} = 0.625 - \frac{48EI}{Pl^3} [\Delta_0 - 0.5D\alpha_t t_p (1 + k_D k_t)], \quad (8)$$

- considering both bending torques and lateral forces

$$\frac{X_1}{P} = \frac{0.25}{2\lambda^2 + 3k(1+\nu)} \left\{ 5\lambda^2 + 6k(1+\nu) - \frac{6\pi ED^2}{Pl} [\Delta_0 - 0.5D\alpha_t t_{wr} (1 + k_D k_t)] \right\}, \quad (9)$$

where $\lambda = l / D$ – relative length of the roll.

The overall estimation of calculation methods with regard to heat expansion of rolls for the 9-roll RLM took making of the following graphs at Figure 2 presenting the relative force at the backup roll, as a function of temperature increase of the working roll with the initial gap 0.1 mm.

According to analyses of the represented graphs, increase in temperature of the working roll up to 50°C results in quite insufficient gap value (preliminary loading) between the rolls, and the results obtained by application of different approaches to solution of this task are relatively equal being in compliance with a well-known classic solution amounting to 0.625. Increase in temperature over 50°C leads to considerable force increase applied to the backup roll, caused by effect of bending torques and lateral forces, i.e. through the ratio taking into account complete strain energy. This effect can be explained by the fact that together with the increase in load suffered by the backup roll, a simultaneous reduction in reaction at the bearing supports of the backup rolls takes place, which also causes subsequent reduction in the share of bending torques in the total strain energy value. The total straightening force is applied to the backup roll, when the working roll temperature is increased by 150° C, and its overload in comparison to a theoretic solution makes 60%. Should the temperature of the working roll increase up to 300° C, the backup roll shall be exposed to force which is almost 1.5 times higher than the complete maximum straightening force at the working roll, and the overload shall make 135% in comparison to a theoretic solution. Together with that reaction of bearing supports shall have same tendency as that of the process load, increasing friction torque in the roll bearings.

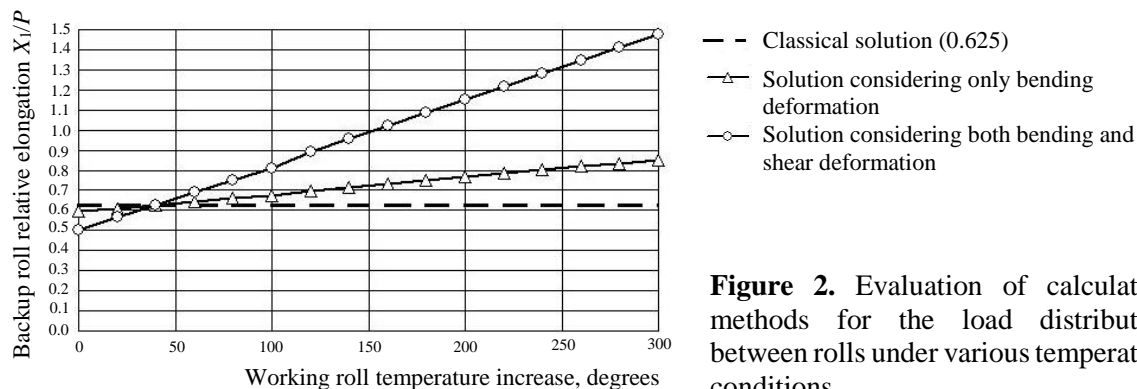


Figure 2. Evaluation of calculation methods for the load distribution between rolls under various temperature conditions.

Apart from overload suffered by the backup roll, loading of RLM roll system presented in the case above leads to change in position of the working roll, thus causing not negligible fluctuations in moving of its operating surface along the width of a sheet to be straightened. This undermines straightening quality of the product.

Conclusions

Summarizing results of the above research, it takes to draw a conclusion as follows:

1. The probable overload of backup roll as much as 2.35 times in respect to a well-known theoretical solution has been justified. The initial gap between rolls at the existing levelling machines shall be set in a way to avoid substantial backup roll overload. For the newly designed equipment it is necessary to consider probable increased estimated load suffered by the backup rolls.
2. Setting of levelling machines shall take it necessary to consider not only total displacement of the crossbeam with the rolls installed on it, but also gaps and heat strain of the rolls.

References

- [1] Nedorezov I V 2003 *Modelling of metal levelling processes at the roll-type levelling machines* (Ekaterinburg: AQUA-PRESS) p 256
- [2] Korolev A A 1985 *Structure and design of machinery and devices of rolling mills* (Moscow: Metallurgy) p 376
- [3] Sorokin V G and Gervasiev M A 2003 *Steels and alloys. Steel grades guide* (Moscow: Internet Engineering) p 608
- [4] Parshin V S, Kostrov V P, Somov B S and at al 2004 *Machinery and facilities used for processing of non-ferrous metals and alloys* (Yekaterinburg: GOU VPO UGTU-UPI) p 383
- [5] Pisarenko G S, Yakovlev A P and Matveev V V 1988 *Reference guide for the strength of materials* (Kiev: Nauk. dumka) p 736